HSRL-2 observations of aerosol variability during an aerosol build-up event in Houston and comparisons with WRF-Chem

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High Spectral Resolution Lidar, HSRL-2

- measures profiles of aerosol optical properties at 3 wavelengths
- Flew on DAQ California, Houston, and Colorado
HSRL-2 measurement products

Aerosol Backscatter 355, 532, 1064 nm

Mixed layer heights inferred from backscatter

Aerosol Extinction 355, 532 nm

September 11, 2013

Aerosol Depolarization 355, 532, 1064 nm

2 lidar ratios

3 angstrom exponents

Aerosol classification uses intensive variables to infer aerosol type

Extensive variables

Intensive variables

Pure Dust
Dusty Mix
Marine
Urban
Smoke
WRF-Chem model run performed by Pablo Saide, U. Iowa, for the SEAC4RS campaign, to provide guidance for flight planning and evaluate model in near-real time

Domain includes the DISCOVER-AQ Houston campaign as well

- WRF-Chem v3.5 CBMZ, 4bin MOSAIC, 12km dx, 52 vertical lvls, and WRF-tracer for emission regions/sectors

- Emissions: anthropogenic, biomass burning (FINN, QFED2) with plume-rise, MEGAN biogenics, dust & sea-salt. MACC boundary conditions

- AOD assimilation (NRL product) every 3 hours, 1 cycle a day (Saide et al., ACP 2013)
Day by day extinction comparison
Extinction comparison, lidar vs. model

Sept 11 AM

Sept 11 PM

HSRL-2
Extinction (532 nm)

WRF-Chem
Extinction (532 nm)

Altitude (km)

Altitude (km)

Hour [UTC]

Hour [UTC]
Extinction comparison, lidar vs. model

Sept 12 AM

Sept 12 PM

Altitude (km)

Altitude (km)

HSRL-2 Extinction (532 nm)

WRF-Chem Extinction (532 nm)
Extinction comparison, lidar vs. model

Sept 13 AM

Sept 13 PM
Insights about aerosol source & type
Aerosol source and type, 6 example layers

Sept 11 AM
- smoke
- anthropogenic

Sept 11 PM
- pure aged wildfire smoke

Sept 12 AM
- agricultural smoke + anthropogenic mix
- pure smoke

Sept 13 AM
- smoke-rich mix
Anthropogenic vs. Smoke
A vs. C
Anthropogenic vs. Smoke: A vs. C

see Burton et al. 2012, AMT, for HSRL aerosol typing

HSRL-2 provisional aerosol classification for DAQ-Houston

- smoke
- anthro
HSRL2 EXT

MODEL EXT

MODEL CO FIRE

MODEL CO ANTHRO

WRF-Chem Backtrajectories

Sept 11 PM

CO Fire along back-trajectory
Mixtures of Agriculture Smoke and Anthropogenic
D vs. F
Mixtures of Agriculture Smoke and Anthropogenic: D vs. F

- **Sept 12 AM**: Agricultural smoke + anthropogenic mix
- **Sept 13 AM**: Smoke-rich mix
Sept 12 AM, residual layer

CO Fire along back-trajectory

CO Anthro along back-trajectory
see Duncan, B. N., et al. *Atmos Environ*, 2014
HSRL-2 Intensive Properties

Sept 12 AM

agricultural smoke + anthropogenic mix

Sept 13 AM

smoke-rich mix

Lidar ratio, 532 nm

Color ratio, 355/532 nm

Intensive Properties

Deer_Park 16:03 - 16:20
Effect of Relative Humidity on lidar intensive properties: setup and assumptions

- Diameter-independent growth factor:
  \[ D_{amb} = g \times D_{dry} \]
  the entire size distribution simply shifts to larger diameters as the particles grows.
- Correction is applied to both real and imaginary parts of refractive index following:
  \[ m_{amb} = \frac{m_{dry} + m_{H2O}(g^3 - 1)}{g^3} \]
  \[ g = \left(1 + \kappa \frac{RH}{100\% - RH}\right)^{\frac{1}{3}} \]
  where \( \kappa \) is the effective hygroscopicity parameter which captures all solute properties.

Less hygroscopic \( \iff \) \( 0 \leq \kappa \leq 1 \) \( \implies \) More hygroscopic

Continental aerosols: \( \kappa = 0.27 \pm 0.21 \)
Clean marine aerosols: \( \kappa = 0.72 \pm 0.24 \) (Pringle et al., 2010, ACP)
Agricultural smoke: \( \kappa = 0.2 \) (Rose et al., 2010, ACP)
Lidar intensive properties: effect of Relative Humidity

\[ \kappa = 0.1 \]

\[ \kappa = 0.3 \]

\[ \text{eff} = 0.11 \text{um}, \text{mR} = 1.45, \text{ml} = 0.005 \]

\[ \text{eff} = 0.16 \text{um}, \text{mR} = 1.51, \text{ml} = 0.01 \]
Pure Smoke
B,C,E
Pure Smoke: B,C,E

Sept 11 AM

Sept 11 PM

pure aged wildfire smoke

Sept 12 AM

pure smoke
Lidar intensive properties for 6 aerosol samples

- Lidar intensive variables vary both within and between types
- Extinction angstrom exponent varies monotonically with size but is noisy
- Lidar ratio related to absorption, but also varies with particle size, as much as angstrom exponent does
- Backscatter color ratios have complicated dependence on size and complex refractive index

Variations within a type due to
- mixing
- humidification
- composition differences due to different sources (for smoke: e.g. wildfire vs. agricultural)
- aging & processing, etc.
- ??
Summary

• HSRL-2 makes horizontally and vertically resolved observations of aerosol layering and diurnal and day-to-day evolution
• High information content in HSRL-2 observations provides the opportunity for model assessment
• HSRL-2 measures a large set of intensive parameters that give information on aerosol type
• Subtleties in HSRL-2 intensive parameters have the potential to give a more nuanced understanding of aerosols
• WRF-Chem model gives context on aerosol sources and transport that helps with interpretation of lidar data
• DISCOVER-AQ Houston case study
  o characterized by large variability in aerosol properties, vertically, temporally and in observed optical properties.
  o included local anthropogenic pollution plus relatively fresh agricultural smoke and aged transported wildfire smoke
EXTRA: WHAT DOES IN SITU SAY?
B: UH Moody Tower, 20130911, 14.84-15.07
C: Smith Point, 20130911, 19.75-19.97
D: Smith Point, 20130912, 14.45-14.71
E: West Houston, 20130912, 15.14-15.43
F: Deer Park, 20130913, 16.05-16.33
DISCUSSION OF VARIABILITY OF INTENSIVE PARAMETERS OF SMOKE
Effective radius

Single Scattering Albedo (532nm)

Total number concentration